



ORIGINAL RESEARCH ARTICLE

EFFECT OF MOISTURE CONTENT AND OIL PALM VARIETIES ON THE COEFFICIENT OF SLIDING FRICTION OF KERNEL AND SHELL ON FIBRE MATERIAL (RUG CANVAS)

V. O. Adepoju^{1*}, A. A. Aderinlewo¹, O. U. Dairo¹ and O. R. Adetunji²

¹Agricultural and Bio-resources Engineering Department, College of Engineering, Federal University of Agriculture, P.M.B 2400, Abeokuta, Ogun State Nigeria;

²Mechanical Engineering Department, College of Engineering, Federal University of Agriculture, P.M.B 2400, Abeokuta, Ogun State, Nigeria;

*Corresponding author's email: adepojuvo@funaab.edu.ng

ARTICLE INFORMATION

Received: 13th October 2025
Revised: 22nd November 2025
Accepted: 24th November 2025

Keywords:

Pisifera, *tenera*
Dura
Frictional properties
Roughness

ABSTRACT

The effect of moisture content of two varieties of palm kernel and shell on the coefficient of sliding friction of the two faces (face A and face B) of a fibre material was determined. Standard procedures were used to determine the moisture content for both kernel and shell of *tenera* and *dura* varieties. The results show that the moisture content of *dura* and *tenera* varieties were 17.4 and 18.2% which were individually adjusted to 9, 13 and 17% by adding 76.3, 39.8 and 3.3 g; and 82.3, 46.4 and 10.6 g distilled water respectively. The angle of repose apparatus was used to determine the coefficient of sliding friction of palm kernel and shell of *dura* and *tenera* varieties on the two faces of fibre material. It was observed that the average values of *dura* palm kernel and palm shell coefficient of sliding friction on the two faces of fibre material ranged from 0.458-0.777 for 9% moisture content; 0.510-0.690 for 13% moisture content and 0.532-0.777 for 17% moisture content. Additionally, the average values of *tenera* kernel and shell coefficient of sliding friction on the two faces of fibre material ranged from 0.546-0.864 for 9% moisture content; 0.506-0.953 for 13% moisture content; and 0.537-0.927 for 17% moisture content. Therefore, we observed that the moisture content of either *dura* palm kernel or *dura* palm shell had significant effect ($p < 0.05$) on the coefficient of sliding friction on face A and face B of the fibre while the moisture content of either *tenera* palm kernel or *tenera* palm shell had insignificant effect ($p > 0.05$) on the coefficient of sliding friction on face A and face B of the fibre. The coefficient of sliding friction on fibre was affected by the moisture content of *dura* variety but not of that *tenera* variety.

© 2025 Faculty of Engineering, University of Maiduguri, Nigeria. All rights reserved.

1.0 Introduction

Oil palm is categorized into three primary varieties based on fruit characteristics, with the *tenera* variety being a hybrid of the *dura* and *pisifera* varieties. Each variety has distinct features; the *dura* variety possesses a thin fruit wall (pericarp) constituting 40-70% of the fruit's mass, alongside an exceptionally thick shell (2-5 mm) and a large nut with a bigger kernel than the others (Adzimah and Seckley, 2009). The *pisifera* variety has a thicker pericarp with a higher potential oil yield. However, it is often female-sterile and typically lacks a kernel, which prevents its use in commercial cultivation for palm kernel oil (PKO), a key industrial material in cosmetics. The hybrid *tenera* variety features a substantial pericarp (approximately 60% of the fruit weight) that is rich in oil, combined with a shell of intermediate thickness (1-2.5 mm) (Adzimah and Seckley, 2009).

The choice of variety depends on the desired product. For palm oil extraction, *tenera* is optimal due to its thickness, oil-rich fruit wall and its relatively easier-to-crack the shell. Conversely, for palm kernel oil (PKO) production, *dura* is preferred because of its larger kernel size, despite the challenge posed by its thicker shell. Interestingly, the rising industrial demand for kernels and their derivatives in Nigerian markets underscores

the necessity for enhanced processing techniques. It is noteworthy that an efficient separation processes of kernels from shells is critical to meet this growing downstream industrial need (Olasumboye and Koya, 2014).

Currently, two primary methods are used which are wet and dry methods. Wet separation uses clay-baths or hydro-cyclones in a liquid medium, leveraging differences in specific gravity. This method is being used commercially but faced a significant drawback through the need to re-dry the recovered kernels for 14-16 hours in a silo to remove absorbed moisture, a step that also serves to sterilize them against mold (Akubuo and Eje, 2002; Adepoju, 2019). In response to the constraints of wet processing, research is focussed on developing dry separation techniques that could be used commercially. The dry methods exploit principles such as gravity, frictional coefficient, speed variation, relative motion, and particle shape. However, many locally produced machines for this purpose remain at the experimental stage or function only as pre-cleaners (Amoah *et al.*, 2007; Adepoju, 2019). Consequently, a detailed investigation into the factors influencing these dry separation principles is required. This study specifically examines how the moisture content in two palm kernel varieties affects their coefficient of sliding friction on a fibrous material (rug).

2. Materials and Methods

2.1 Materials

The materials used to determine the moisture content and coefficient of sliding friction of palm kernel and shell were: oven, *dura* palm kernel and shell, *tenera* palm kernel and shell, angle of repose apparatus, desiccator (180 ml), digital weighing balance (Scout Pro (SPU2001) electronic balance with accuracy 0.1 g) and 2 hp powered horizontal centrifugal cracker.

2.2 Method

2.2.1 Sample collection

Tenera nuts used in the study was collected from the Directorate of University Farms (DUFARMS), Federal University of Agriculture, Abeokuta (FUNAAB) while *dura* nuts were collected from Ogun State Ministry of Agriculture, Eweje, Odeda, Abeokuta, Ogun State.

2.2.2 Sample preparation

The nuts of *dura* and *tenera* were manually cleaned from unwanted materials such as cell debris, stones and dirt. Then, the nuts were cracked using centrifugal cracker into palm kernels and shells.

2.2.3 Determination of moisture content

The moisture content of palm kernels and shells from the *dura* and *tenera* varieties was determined following the ASAE standard (1998) for oil seeds, as cited by Orhevba *et al.* (2013). The analysis was conducted in the Crop Processing Laboratory of the Department of Agricultural and Bio-Resources Engineering, College of Engineering, at the Federal University of Agriculture, Abeokuta (FUNAAB), Nigeria. For each variety, a 1.20 kg sample of the cracked kernel-shell mixture was weighed and oven-dried at 105°C. After an initial drying period of six hours, the samples were transferred to a desiccator to cool, preventing moisture reabsorption from the atmosphere. Following this, the mass of each sample was recorded at one-hour intervals until a constant mass was achieved, indicating that all moisture had been removed. The initial moisture content was then calculated on a wet basis using Equation (1). The final dried kernel-shell mixture was divided into three (3) portions each for the two varieties.

$$mc = \frac{w_1 - w_2}{w_1} \quad |$$

Where mc is the moisture content, w_1 is the initial mass and w_2 is the final mass.

2.2.4 Moisture content adjustment

A calculated amount of distilled water (76.3, 39.8 and 3.3 g; and 82.3, 46.4 and 10.6g) was added to the six (6) samples of the mixture of kernels and shells of the two varieties to bring them to the desired moisture contents of 9, 13 and 17% w.b. using equation (2) as used by Olayanju (2002) and sealed in separate polythene

bags. Afterwards, the polythene was kept in refrigerator at 5°C temperature for at least one week to ensure moisture uniform distribution according to Davies and Zibokere (2011).

$$Q = \frac{A(b - a)}{(100 - b)} \quad 2$$

Where A is Initial mass of the sample, g; a is initial moisture content of the sample, %wet basis (w.b.); b is final (desired) moisture content of sample % (w.b.); Q is mass of water to be added, g.

2.2.5 Determination of coefficient of sliding friction

The angle of repose apparatus used for the determination of coefficient of sliding friction of *dura* and *tenera* varieties as used by Adepoju et al. (2023) is shown in the Plate 1. Palm kernels and shells of each variety were loaded on to an open-ended rectangular box, 100 × 50 × 30 mm made of cardboard placed on the tilting board. In order to allow the free movement of the sample, one of the edges of the box was not fixed to allow for the movement of the crop product component on the board surface covered with fibre material as shown in the Plate 2. An adjustable screw jack was positioned under the apparatus for controlling the angle of inclination. The box was loaded in turns with the kernels and shells of the two varieties. The tilt angle at initial sliding of the box was noted for five readings and averaged. The coefficient of sliding friction was calculated with the Equation (3).

$$\mu = \tan\theta \quad 3$$

where μ is the coefficient of friction and θ is the angle of inclination (degree).



Plate 1: Coefficient of sliding friction determination apparatus

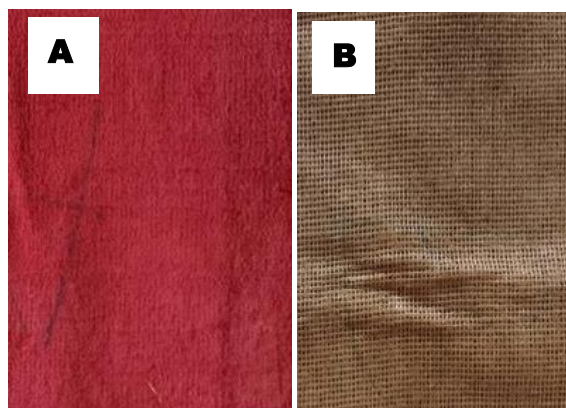


Plate 2: Two faces of the fibre material (rug)

2.2.5 Experimental design

The experimental design used was 3×2×2×2×5 factorial experiment where three (3) moisture contents was used for two (2) varieties of two (2) samples (palm kernel and shell) on two (2) faces of fibre material at five (5) replicates. The total runs for the determination of coefficient of sliding friction was one hundred and twenty (120).

2.2.6 Data analysis

The coefficient of sliding friction obtained for the three moisture levels, two varieties, products and faces each of fibre material at five (5) replicates were analyzed using the analysis of variance (ANOVA). Separation of means was carried out by the use of Tukey Method.

3. Results and Discussion

The results show that moisture content of *dura* and *tenera* varieties was determined to be 17.4 and 18.2% which were adjusted to 9, 13 and 17% by adding 76.3, 39.8 and 3.3 g; and 82.3, 46.4 and 10.6g distilled water respectively. It was observed that the *dura* kernel coefficients of sliding friction for 9, 13 and 17% moisture contents (w.b.) for face A and face B of the fibre material were 0.471, 0.592 and 0.611; and 0.458, 0.510 and 0.532 respectively (Table 1). It was observed that the coefficient of sliding friction increased as the moisture content increased from 9 to 17% for both faces. The coefficient of sliding friction for face A was higher than the coefficient of sliding friction for face B (Table 1). In addition, the *dura* shell coefficients of sliding friction for 9, 13 and 17% moisture contents (w.b.) for face A and face B were 0.777, 0.675 and 0.777; and 0.650, 0.690 and 0.606 respectively. For the face A, it was observed that the coefficient of sliding friction decreased as the moisture content increased from 9 to 13% but increased as the moisture content increased from 13 to 17%. For the face B, the coefficient of sliding friction increased as the moisture content increased from 9 to 13% but decreased as the moisture content increased from 13 to 17%. The coefficient of sliding friction for face A was higher than coefficient of sliding friction for face B (Table 1).

The coefficient of sliding friction of face A was higher than that of face B for both palm kernel and shell because the surface of face A was rougher than the surface of face B and that, will influence the force of resistance to be overpowered before the palm kernel and shell can slide or roll. Therefore, the surface roughness of face A of fibre material increased the frictional force that prevent either palm kernel or shell from sliding or rolling down the inclined plane. Also, the coefficient of sliding friction of *dura* palm shell on any face of the fibre material was higher than the coefficient of sliding friction of *dura* palm kernel. The surface roughness of palm shell was higher than that of palm kernel and this will affect their forces of resistance, known as frictional force, to be overpowered.

Table 1: Average values of *dura* kernel and shell coefficient of sliding friction on fibre material at different moisture content

Moisture content (%)	<i>Dura</i> palm kernel			
	Face A		Face B	
	θ°	μ	θ°	μ
9	25.2±1.92	0.471±0.04	24.6±1.67	0.458±0.04
13	30.6±1.67	0.592±0.04	27.0±1.41	0.510±0.03
17	31.4±1.67	0.611±0.04	28.0±1.22	0.532±0.03
Moisture content (%)	<i>Dura</i> palm shell			
	Face A		Face B	
	θ°	μ	θ°	μ
9	37.8±1.79	0.777±0.05	33.0±1.73	0.650±0.04
13	34.0±1.87	0.675±0.05	34.6±1.52	0.690±0.04
17	37.8±1.92	0.777±0.05	31.2±1.79	0.606±0.04

The *tenera* kernel coefficients of sliding friction for 9, 13 and 17% moisture contents (w.b.) for face A and face B were 0.611, 0.606 and 0.621; and 0.546, 0.506 and 0.537 respectively (Table 2). It was observed that the coefficient of sliding friction decreased as the moisture content increased from 9 to 13% but increased as the moisture content increased from 13 to 17% for both faces. The coefficient of sliding friction for face A was higher than the coefficient of sliding friction for face B (Table 2).

The *tenera* shell coefficients of sliding friction for 9, 13 and 17% moisture contents (w.b.) for face A and face B were 0.864, 0.953 and 0.927; and 0.805, 0.805 and 0.828 respectively (Table 2). It was observed that the coefficient of sliding friction increased as the moisture content increased from 9 to 13% but decreased as the moisture content increased from 13 to 17% for the face A while the coefficient of sliding friction remained the same as the moisture content increased from 9 to 13% but increased as the moisture content increased from 13 to 17% for the face B. The coefficient of sliding friction for face A was higher than the coefficient of sliding friction for face B because the surface of face A was rougher than the surface of face B (Table 2). The

degree of roughness of a material would determine the force required to overcome the resistant force of the material in order for an object to be able to slide or roll. Furthermore, the coefficient of sliding friction of *tenera* palm shell on any face of the fibre material was higher than the coefficient of sliding friction of *tenera* palm kernel.

Notably, the coefficients of sliding friction of *tenera* variety of either palm kernel or shell were higher than that of *dura* variety. This is because there were differences in their masses and according to Adepoju *et al.* (2023), “the mass of *dura* variety of either palm kernel or palm shell was higher than the mass of *tenera* variety”. They further explained that their masses would affect the force of gravity acting on them which would affect their ability to roll or slide down the plane. Since *dura* variety of either palm kernel or palm shell had the higher mass, it would roll or slide down at a lower angle of inclination than the *tenera* variety with lower mass.

Table 2: Average values of *tenera* kernel and shell coefficient of sliding friction on fibre material at different moisture content

Moisture content (%)	<i>Tenera</i> palm kernel			
	Face A		Face B	
	θ°	μ	θ°	μ
9	31.4±0.89	0.611±0.02	28.6±1.34	0.546±0.03
13	31.2±0.837	0.606±0.02	26.8±1.64	0.506±0.04
17	31.8±1.79	0.621±0.04	28.2±1.64	0.537±0.04
Moisture content (%)	<i>Tenera</i> palm shell			
	Face A		Face B	
	θ°	μ	θ°	μ
9	40.8±1.79	0.864±0.05	38.8±1.64	0.805±0.05
13	43.6±1.34	0.953±0.04	38.8±1.79	0.805±0.05
17	42.8±1.79	0.927±0.06	39.6±0.89	0.828±0.03

For *dura* kernel on the face A of the fibre material, the moisture content had significant effect ($p < 0.05$) on the coefficient of sliding friction of *dura* kernel on face A of the fibre material (Table 3). This means that the coefficients of sliding friction of at least two moisture contents of *dura* kernel were different from each other on face A of the fibre material (Table 3). For *dura* kernel on the face B of the fibre material, the moisture content had significant effect ($p < 0.05$) on the coefficient of sliding friction of *dura* kernel on face B of the fibre. This means that the coefficients of sliding friction of at least two moisture contents of *dura* kernel were different from each other on face B of the fibre material (Table 3).

For *tenera* kernel on the face A of the fibre material, the moisture content had no significant effect ($p > 0.05$) on the coefficient of sliding friction of *tenera* kernel on face A of the fibre. This means that the coefficients of sliding friction on face A of the fibre were significantly the same at any moisture content of the *tenera* kernel (Table 3). For *tenera* kernel on the face B of the fibre material, the moisture content had no significant effect ($p > 0.05$) on the coefficient of sliding friction of *tenera* kernel on face B of the fibre. This means that the coefficients of sliding friction on face B of the fibre were significantly the same at any moisture content of the *tenera* kernel (Table 3).

Table 3: Summary of analysis of variance of the effect of moisture content of *dura* kernel and *tenera* kernel on coefficient of sliding friction for both faces of the fibre material

Sample/face	Source	DF	SS	MS	F-Value	P-Value
<i>Dura</i> kernel on the face A	Moisture Content	2	0.05758	0.028792	17.96	0.000
	Error	12	0.01923	0.001603		
	Total	14	0.07682			
<i>Dura</i> kernel on the face B	Moisture Content	2	0.01433	0.007163	7.29	0.008
	Error	12	0.01180	0.000983		
	Total	14	0.02612			
<i>Tenera</i> kernel on the face A	Moisture Content	2	0.000581	0.000291	0.32	0.732
	Error	12	0.010892	0.000908		
	Total	14	0.011473			
<i>Tenera</i> kernel on the face B	Moisture Content	2	0.004409	0.002204	1.83	0.203
	Error	12	0.014480	0.001207		
	Total	14	0.018888			

For *dura* shell on the face A of the fibre material, the moisture content had significant effect ($p < 0.05$) on the coefficient of sliding friction of *dura* shell on face A of the fibre. This means that the coefficients of sliding friction of at least two moisture contents of *dura* shell were different from each other on face A of the fibre material (Table 4). For *dura* shell on the face B of the fibre material, the moisture content had significant effect ($p < 0.05$) on the coefficient of sliding friction of *dura* shell on face B of the fibre. This means that the coefficients of sliding friction of at least two moisture contents of *dura* shell were different from each other on face B of the fibre material (Table 4). For *tenera* shell on the face A of the fibre material, the moisture content had no significant effect ($p > 0.05$) on the coefficient of sliding friction of *tenera* shell on face A of the fibre. This means that the coefficients of sliding friction on face A of the fibre were significantly the same at any moisture content of the *tenera* shell (Table 4). For *tenera* shell on the face B of the fibre material, the moisture content had no significant effect ($p > 0.05$) on the coefficient of sliding friction of *tenera* shell on face B of the fibre. This means that the coefficients of sliding friction on face B of the fibre were significantly the same at any moisture content of the *tenera* shell (Table 4).

Table 4: Summary of analysis of variance of the effect of moisture content of *dura* shell and *tenera* shell on coefficient of sliding friction of the two faces of the fibre material

Sample/face	Source	DF	SS	MS	F-Value	P-Value
<i>Dura</i> shell on the face A	Moisture Content	2	0.03427	0.017134	6.80	0.011
	Error	12	0.03023	0.002519		
	Total	14	0.06449			
<i>Dura</i> shell on the face B	Moisture Content	2	0.01771	0.008857	5.09	0.025
	Error	12	0.02086	0.001738		
	Total	14	0.03858			
<i>Tenera</i> shell on the face A	Moisture Content	2	0.02084	0.010418	3.80	0.053
	Error	12	0.03287	0.002739		
	Total	14	0.05371			
<i>Tenera</i> shell on the face B	Moisture Content	2	0.001698	0.000849	0.46	0.641
	Error	12	0.022067	0.001839		
	Total	14	0.023765			

The summary of separation of means for the coefficient of sliding friction on the fibre material using Tukey Method is shown in the Table 5. For *dura* palm kernel on the face A of the fibre, the coefficient of sliding friction at 9% moisture content was significantly different from the coefficients of sliding friction at both 13% and 17% moisture contents that were insignificantly different from each other (Column 2). For *dura* palm kernel on the face B of the fibre, the coefficients of sliding friction at 9% and 17% moisture contents were significantly different from each other but were significantly the same with the coefficient of sliding friction at 13% moisture content (Column 3). For *dura* palm shell on the face A of the fibre, the coefficient of sliding friction at 13% moisture content was significantly different from the coefficients of sliding friction at both 9% and 17% moisture contents that were not significantly different from each other (Column 4). For *dura* palm shell on the face B of the fibre, the coefficients of sliding friction at 13% and 17% moisture contents were significantly different from each other but were significantly the same with the coefficient of sliding friction at 9% moisture content (Column 5).

Table 5: Summary of separation of means using Tukey Method for the coefficient of sliding friction on the fibre material.

Moisture Content (%)	<i>Dura</i> kernel A	<i>Dura</i> kernel B	<i>Dura</i> shell A	<i>Dura</i> shell B
9	0.471±0.04 ^a	0.458±0.04 ^a	0.777±0.05 ^a	0.650±0.04 ^{ab}
13	0.592±0.04 ^b	0.510±0.03 ^{ab}	0.675±0.05 ^b	0.690±0.04 ^a
17	0.611±0.04 ^b	0.532±0.03 ^b	0.777±0.05 ^a	0.606±0.04 ^b

Means that do not share a letter are significantly different

4. Conclusion

This study obtained values for coefficient of sliding friction as affected by the moisture contents of palm kernel and palm shell of the two varieties on two faces of fibre material which are needed to understudy canvas materials for frictional separation. Palm shell demonstrated a higher coefficient of sliding friction than palm kernel across both *dura* and *tenera* varieties. Furthermore, the *tenera* variety exhibited greater frictional

properties than *dura*. A significant influence of moisture content on friction was observed for the *dura* variety, whereas its effect on the *tenera* variety was statistically insignificant.

References

- Adepoju, VO. 2019. Design and Fabrication of a Draper Separator for Palm Kernel and Shell, Unpublished Master of Engineering Dissertation, Department of Agriculture and Bio-Resources Engineering, Federal University of Agriculture, Abeokuta.
- Adepoju, VO., Aderinlewo, AA., Dairo, OU., Adetunji, OR., and Babalola, AA. 2023. Determination of some physical properties of palm kernel and shell in relation to frictional separation. *Journal of Natural Science, Engineering and Technology*, 22(1):39-52.
- Adzimah, SK. and Seckley, E. 2009. Modification in the Design of an already Existing Palm Nut-Fibre Separator. *African Journal of Environmental Science and Technology*, 3(11):387-398.
- Akubuo, CO. and Eje, BE. 2002. Palm Kernel and Shell Separator. *Biosystems Engineering*, 81(2), 193-199, doi: 10.1016/j.biosystemseng.2001.0029.
- Amoah, JY., Aggey, M. and Annumu, S. 2007. Cracked Mixture Sieving Rates and Efficiencies in Small-scale Palm Nut Processing in Ghana. *Ghana Journal of Science*, 47: 69-81.
- ASAE Standards (1998). Moisture measurement – unground grain and seeds. *American Society of Agricultural Engineers (ASAE)*, S352.2:551.
- Davies, RM. and Zibokere, DS. 2011. Effect of moisture content on some physical and mechanical properties of three varieties of cowpea (*vigna unguiculata (L) walp*). *Agric Eng Int. CIGR Journal*, 13(1):1-8.
- Olasumboye, A. and Koya, O. 2014. A Rotary Separator for the Dry Mixture of Palm Kernel and Shell. *Innovative Systems Design and Engineering*, Vol.5, No. 7, pp32-41
- Olayanju, TMA. 2002. Design, Fabrication and Evaluation of a Beniseed (*Sesamum Indicum L.*) Oil Expeller. An Unpublished PhD. Thesis at the Department of Agricultural Engineering, University of Ibadan, Nigeria.
- Orhevba, BA., Chukwu, O., Osunde, ZD., and Ogwuagwu, V. 2013. Influence of moisture content of the yield of mechanically expressed neem seed kernel oil. *Academic Research International*, 4 (5): 252 – 257.